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**BUFFER STRIPS FOR STREAM TEMPERATURE CONTROL**

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## SUMMARY

During clearcut logging, complete removal of the forest canopy and the shade it provides to small streams can cause large increases in water temperature. Such increases in temperature can be prevented if buffer strips of vegetation are left along the stream to provide shade. The purposes of this paper are to define the characteristics of buffer strips that are important in regulating the temperature of small streams and to describe a method of designing buffer strips that will insure no change in stream temperature as a result of logging and, at the same time, minimize the amount of commercial timber left in the strip.

Commercial timber volume alone is not an important criterion for temperature control. Further, the width of the buffer strip is also not an important criterion. For the small streams studied as part of this research, the maximum shading ability of the average buffer strip was reached within a width of 80 feet. Specifying standard 100- to 200-foot buffer strips for all streams generally will include more timber than necessary. The canopy density along the path of incoming solar radiation best describes the ability of the buffer strip to control stream temperature. An estimate of this value can be obtained easily by foresters laying out buffer strips in the field and will insure proper design of the buffer strip for control of stream temperature.

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## BUFFER STRIPS FOR STREAM TEMPERATURE CONTROL

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## INTRODUCTION

The purposes of this research paper are to define the characteristics of buffer strips that are important in regulating the temperature of small streams and to describe a method of designing buffer strips that will insure no change in temperature and, at the same time, minimize the amount of commercial timber left in the strip to provide the necessary shade.

Research shows that clearcut logging can increase significantly the temperature of small streams (5, 9, 11). Temperature increases from 6 to as much as 28 degrees F have been reported. The magnitude of the increase is dependent upon stream characteristics such as discharge or flow, surface area exposed to sunlight, and amount of radiation received from the sun. Brown (3) showed that heat received by a stream exposed by clearcutting may be from five to six times that received when the stream was shaded.

Changes in temperature may influence fish habitat in several ways. As temperature increases, the ability of stream water to hold dissolved oxygen declines. Aquatic pathogens also may find warmer water more conducive to development. At extremely high temperatures, fish may be unable to survive because their lethal limit has been reached. High temperature of the water also may influence the metabolic processes of fish and, although it may not cause direct mortality, it may adversely affect growth, development, and body condition. Finally, water temperature may alter the species composition of a stream as temperatures shift from the optimum range for one species to the optimum range for another. The impact of these changes in habitat on the productivity of a particular stream is difficult to predict because of the interaction of so many variables. Most standards for water quality, however, severely restrict the amount of change in temperature permissible because of the many possible consequences.

Increases in the temperature of small streams can be prevented during and after logging by leaving a protective strip of vegetation alongside the stream to provide shade. The efficiency of this strip in controlling water temperature has been demonstrated in several studies (5, 6, 11). Guidelines for the protection of streams in logged watersheds have recommended buffer strips for temperature control (7, 8, 10, 12). In one guide (7), a standard width is specified. This standardization results in utilization of the timber resource that is less than optimum by creating buffer strips larger than necessary for temperature control. In other guides (8, 12), variable widths are suggested. Only generalized specifications are given, however.

## STUDY SITES AND METHODS

### Study Sites

Study sites were located on nine small mountain streams in Oregon. Three streams, Little Rock, Francis, and Reynolds Creeks, are in the Umpqua National Forest in the southern Cascade Mountains. Five others, Deer, Lake, Grant, Griffith, and Savage Creeks are in the Siuslaw National Forest in the Coast Range. The remaining stream, Needle Branch, is on land owned by Georgia Pacific Corporation in the Coast Range.

The streams all flow through or are adjacent to clearcuttings. All have a strip of vegetation that separates them from the clearcuttings. On Needle Branch, the strip consists of red alder, which has grown up rapidly along the stream after clearcutting. All are valuable for fish production and have a potentially large problem of temperature.

### Methods

Discharge, stream travel time past the clearcutting, surface area of the stream in the clearcutting, and water temperature above and below the clearcutting were measured.

The buffer strips were described by the volume of commercial timber in the strip, the average strip width, and the density of forest canopy (Table 1). Volume of commercial timber was determined by conventional timber cruising techniques. Average strip width was measured with a tape. Canopy density was measured along the path of incoming solar radiation rather than vertically, as is done normally. This measure of canopy density, called angular canopy

Table 1. A Comparison of Various Measured and Calculated Parameters for the Study Streams.

Stream	Temperature change		Heat blocked, $\Delta H$	Angular canopy density, ACD	Average strip width, Ft	Timber volume/foot of strip	Maximum temperature		
	Pre-dicted	Ob-served					Ob-served	Pre-dicted	
	F	F					F	F	
	$\frac{BTU}{ft^2 \text{ min}}$								
Little Rock	10.1	6.0	1.4	73.6	47	4.0	50	72.0	76.0
Upper Reynolds	4.8	7.5	0.0	18.3	10	-2.7	0	74.5	72.0
Lower Reynolds	1.6	3.0	0.0	46.9	40	-1.4	42	71.5	70.0
Upper Francis	41.9 <sup>2</sup>	2.0	3.8	75.9	50	39.9	78	62.0	101.9
Upper Deer	7.6	4.0	2.0	80.3	100	3.6	11	57.0	60.5
Lower Deer	9.0	1.0	3.7	78.3	100	8.0	102	56.0	64.0
Lake	12.5	3.0	3.1	77.7	30	9.5	2	61.0	70.5
Upper Grant	4.4	2.0	2.3	59.1	60	2.4	42	55.0	57.5
Lower Grant	4.3	1.0	3.2	65.2	60	3.3	42	55.0	58.5
Griffith	21.7	3.0	3.5	79.1	50	18.7	137	62.0	80.5
Upper Needle Branch	32.0 <sup>2</sup>	9.0	2.8	55.6	8	23.0	0	67.0	90.0

<sup>1</sup> The predicted temperature change minus the observed temperature change.

<sup>2</sup> Predicted from the equilibrium temperature calculation.

density and abbreviated ACD, was estimated with the device shown in Figure 1. This instrument consists of a 1-foot-square plane mirror marked with a 3-inch grid. The mirror can be tilted so that the observer, looking down vertically on the mirror, will see the canopy along a predetermined angle. The mirror is canted to an angle equal to the complement of the maximum angle of the sun for the time of year when the temperature problem is greatest, generally July or August. This period will vary depending on streamflow regimes and climate. Usually, the highest temperatures occur during the period with the lowest streamflow.

Angular canopy density was measured at 100-foot intervals. The angular canopy densiometer was placed in the stream, pointed south, leveled, and tilted to the proper angle. Angular canopy density then was determined by counting the number of squares and fractions of squares on the mirror covered by the canopy. This number was converted to percentage of canopy coverage.



Figure 1. The angular canopy densiometer.

Linear and nonlinear regression analyses were used to determine the buffer strip characteristic that had the greatest effect in controlling stream temperature. The dependent variable in each analysis was the heat blocked by the buffer strip. The heat blocked by the strip ( $\Delta H$ ) was calculated by two methods. One was based upon a temperature prediction formula developed by Brown (4) and the other upon equilibrium temperature formulae developed by Brady, Graves, and Geyer (1). Both methods utilize the concept that the difference between the observed change in temperature and that predicted must be because of the protective ability of the buffer strip. In other words, the strip intercepts the quantity of heat necessary to raise the temperature of the water from the observed to the predicted levels. The effectiveness of the buffer strip increases as the amount of heat blocked ( $\Delta H$ ) increases. Details for calculating  $\Delta H$  are presented by Brazier (2).

## RESULTS

### Commercial Timber Volume and Buffer Strip Efficiency

Hypothetically, there should be little relation between commercial timber volume and  $\Delta H$ . This is because commercial timber volume alone has no relation to the shading ability of the vegetation in the buffer strip. Species such as salmonberry have no commercial volume, but are often excellent sources of shade for small streams. In contrast, a strip composed only of a few large trees with a large commercial volume may have little protective ability because of spacing. Eventually, on any given stream, as the commercial volume per foot of stream increases, the spacing of the trees will decrease so that the strip will have a positive effect on stream temperatures.

The relation between volume of commercial timber and efficiency of the buffer strip is illustrated in Table 2 and Figure 2. One stream, Savage Creek, received no shade from the conifers in the strip; they were on the north side of the stream. Linear regression analysis was used to describe the relation between commercial timber volume and  $\Delta H$  in Figure 2. The hypothetical limits are shown on this figure as the upper horizontal line, which indicates maximum shading regardless of volume, and the lower curved line, which indicates some minimum shade level. Two streams, noted by circles, are not included in the analysis because these streams were physiographically different from the other streams. Both streams lie in

Table 2. A Comparison of the Commercial Volume of the Buffer Strips in Conifers and the Percentage of Shade Contributed by the Conifers.

Stream	Commercial volume in conifers <sup>1</sup> Bd ft	Shade contributed by conifers Percent
Little Rock	75,000	87.5
Lower Reynolds	25,118	33.0
Upper Francis	187,885	79.2
Lower Francis	55,145	83.3
Lower Deer	138,830	25.0
Upper Grant	36,073	10.0
Lower Grant	36,073	10.0
Griffith	411,625	74.2
Savage	194,980	0.0

<sup>1</sup>The other buffer strips were composed entirely of hardwood and brushy species of vegetation.

broad, flat valleys rather than V-shaped canyons. They are included in Figures 2, 3, and 4 to illustrate the influence of topography on the amount of radiation received by streams. On these two streams, canyon walls do not help shade the stream and additional energy reaches the stream by side lighting. Thus, the energy blocked ( $\Delta H$ ) is less. The analysis showed a poor relation ( $R^2 = 0.2661$ ) between commercial volume per foot of stream and  $\Delta H$ .

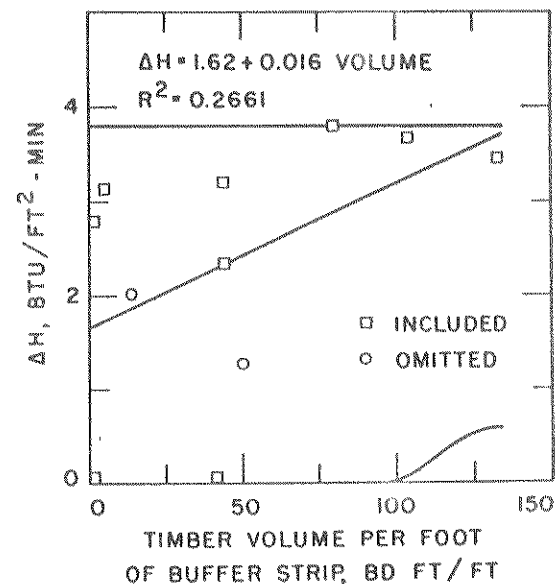


Figure 2. The observed relation between buffer strip volume and heat blocked ( $\Delta H$ ).

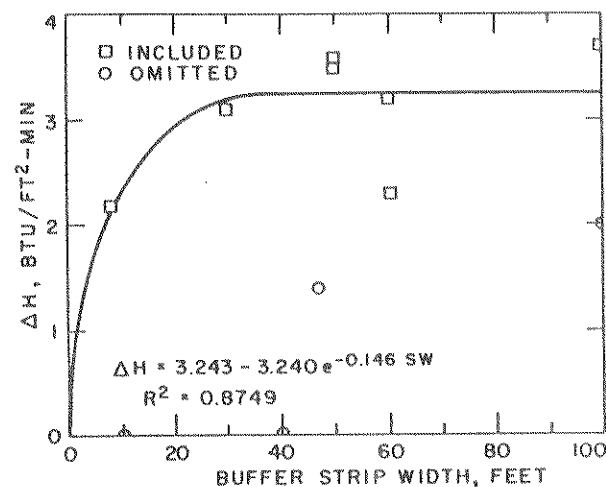


Figure 3. The observed relation between buffer strip width (SW) and heat blocked ( $\Delta H$ ).

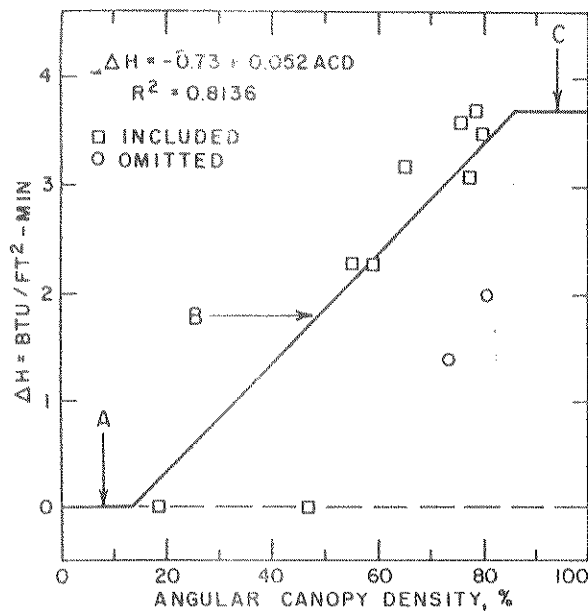


Figure 4. The observed relation between angular canopy density (ACD) and heat blocked ( $\Delta H$ ).

#### Buffer Strip Width and Efficiency

Strip width, alone, should have little to do with the ability of the vegetation in the strip to shade the stream. Strip width is related to the effectiveness of buffer strips through a complex interrelation of canopy density, canopy height, stream width, and stream discharge. On small streams such as those included in this study, the relation between  $\Delta H$  and strip width can be viewed as asymptotic. The quickness with which the relation approaches some asymptote is a function of the type of vegetation contained in the strip. Vegetation such as salmonberry provides only a narrow band of shade along the stream because of its height. Strips wider than this narrow section should not improve in effectiveness. Trees generally have canopies of lower density than species such as salmonberry and, thus, require more space to provide the same shade.

The relation between strip width and efficiency is shown in Figure 3. Four sections were omitted from the analysis: two because of channel shape and two because of difficulties in defining precisely the strip width because of irregularity. Nonlinear regression analysis was used to analyze this relation. The curve in Figure 3 was forced through the origin. The high value of  $R^2$  (0.8749) indicates that the curve is a good approximation of the relation.

#### Angular Canopy Density and Buffer Strip Efficiency

The hypothetical relation between  $\Delta H$  and angular canopy density,  $ACD$ , may be considered logistic in nature. Low canopy densities, although reducing the solar radiation incident to the stream in direct proportion to the percentage of sky covered, do not provide sufficient shade for the effect to be measurable. Thus, the value for  $\Delta H$  is zero until some measurement threshold is reached.

Above this value, there should be a direct, linear relation between  $\Delta H$  and  $ACD$  until the canopy approaches full closure. As the canopy density approaches 100 percent, additional

increments of density should block less radiation than the previous increment. This is because, at high canopy densities, the possibility for reflection and absorption of the incident radiation increases, which allows mostly diffuse radiation to reach the stream.

The level of this diffuse radiation is controlled by factors other than canopy density. The volume of vegetation in the canopy influences the amount of transmission. The thicker canopies provided by conifers are more efficient traps of radiation than the thin canopies of hardwoods, even though the canopy densities may be the same. Thus, with greater canopy density, the relation between  $\Delta H$  and  $ACD$  should approach some asymptote at a level less than complete blockage of incident radiation. Values of  $\Delta H$  for undisturbed canopies are in the range from 3.0 to 3.6 British thermal units per square foot per minute ( $BTU\ ft^{-2}\ min^{-1}$ ) (3.6). This corresponds with values calculated in this study.

The relation between angular canopy density and  $\Delta H$  is shown in Figure 4. Two streams again are omitted from the analysis because of the surrounding terrain. Problems with the computer programs prevented fitting a logistic curve to the data. For this reason, a straight-line approximation to the logistic curve was used. Segment A represents the  $ACD$  values below the measurement threshold level, which occurs at about 14 percent with these data. This point was determined by the zero intercept of the linear regression analysis used for segment B. Line segment B is the section of increasing buffer-strip effectiveness with increasing  $ACD$ . The line fits the data well with an  $R^2$  value of 0.8939. Segment C is the area of maximum protection. The maximum value was determined from data on net radiation from protected streams as explained above. Once the maximum protection has been reached, increases in  $ACD$  offer no greater protection.

The relation between angular canopy density and strip width for all the streams studied is illustrated in Figure 5. This figure provides additional evidence that for small streams, narrow buffer strips may be sufficient to provide stream protection. For the streams included in this study, the maximum angular canopy density is reached within a width of 80 feet. Moreover, 90 percent of that maximum is reached within 55 feet.

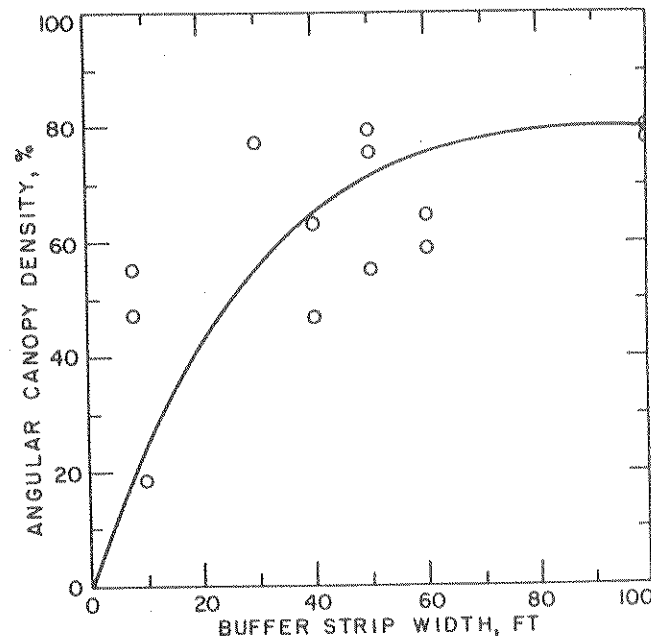


Figure 5. The relation between buffer strip width and angular canopy density.

### Establishing Buffer Strips

Buffer strips can be designed easily with the results of this study so that no change in the natural temperature regime will occur after logging, and the volume of commercial timber left in the strip will be minimized. The procedure for laying out such a strip is as follows:

Place the angular canopy densiometer in the stream. Level it, point the mirror south, and tilt it to the complement of the solar angle for July or August.

Look into the mirror and determine which trees and shrubs are providing shade for the stream. Mark these for inclusion in the strip.

Move to the next station and repeat the procedure. The distance between stations is a matter of judgment, but should be no more than 100 feet. Fewer stations are required in uniform conditions of vegetation and topography. In many instances, the shade contribution of each tree must be evaluated if it is particularly valuable.

The buffer-strip boundaries determined by this method later can be modified to provide protection from destruction of the stream bank or accumulation of debris in the channel if the situation demands. A strip designed with the angular canopy densiometer probably should be regarded as minimum for these purposes.

### CONCLUSIONS

The results of this study lead to some interesting conclusions about designing buffer strips for temperature control.

Commercial timber volume alone is not an important criterion for temperature control. The effectiveness of buffer strips in controlling temperature changes is independent of timber volume.

Width of the buffer strip, alone, is not an important criterion for control of stream temperature. For the streams in this study, the maximum shading ability of the average strip was reached within a width of 80 feet; 90 percent of that maximum was reached within 55 feet. Specifying standard 100- to 200-foot buffer strips for all streams, which usually assures protection, generally will include more timber in the strip than is necessary.

Angular canopy density is correlated well with stream-temperature control. It is the only single criterion the forester can use that will assure him adequate temperature control for the stream without overdesigning the buffer strip.

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